APPENDIX C

Air Sparging and Pulsed Air Biosparging Evaluation

TECHNICAL MEMORANDUM

To: Steve Smith, Solutia Inc.

From: Michal Rysz, Travis McGuire, Charles Newell, James Kearley
GSI Environmental, Inc.

Re: **Air Sparging and Pulsed Air Biosparging Evaluation**
Sauget Area 1, Sauget and Cahokia, Illinois

EXECUTIVE SUMMARY

As requested by Solutia, GSI Environmental Inc. (GSI) has conducted a planning-level comparison of two potential groundwater remediation technologies for Sauget Area 1 sites:

- Air sparging (AS)
- Pulsed air biosparging (PABS)

The analysis showed that while the AS system has a somewhat faster mass removal rate, the PABS system is simpler, more cost effective, and will not require a soil vapor extraction (SVE) system.

Key features associated with the AS system:

- The continuous injection of atmospheric air will result in initial rapid contaminant volatilization (approximately first 60 days).
- The continuous delivery of air containing oxygen (higher volume than the PABS system) will more effectively stimulate the aerobic degradation of contaminants present at the site.

Key features associated with the PABS system:

- The injection well network for the PABS system will the same as the AS system.
- Limited operation time (i.e. short duration injections) of the AS system will require less energy input than the continuously operating AS system.
- Air injection will be controlled such that an SVE system and the associated vapor treatment system would not be required.

This analysis was a planning-level effort based on guidance documents and limited site-specific data (soil and groundwater contaminant concentrations). If it is determined that either AS or PABS is required, then a pilot test of the selected system is recommended prior to full- scale design. The pilot test would provide information critical for the proper operation of the sparging system (i.e. radial zone of air distribution, optimal injection frequency and duration), and also provide data for a more detailed system performance analysis.

1.0 INTRODUCTION

Air sparging (AS) and pulsed air biosparging (PABS) are being considered as potential remedial technologies for the in-situ treatment of the DNAPL residual areas at Sites G, H, and I at Sauget Area 1. The systems are envisioned to consist of a series of dual nested injection wells, and additional equipment associated with the system operation, installed at locations targeting previously identified DNAPL areas. This memorandum presents: i) a comparison of the modeled performance of the AS and PABS systems based on the preliminary conceptual design and available site specific data; and ii) planning-level cost estimates for implementation of the two technologies developed using conceptual design data and the Remedial Action Cost Engineering and Requirements (RACER) software (RACER 2008).

AS relies on both volatilization and in-situ aerobic biodegradation to remove mass from the subsurface. After the first couple of weeks, however, the mass removal is dominated by biodegradation resulting from the diffusion of oxygen from air channels to areas not contacted by the air channels. Most air sparging systems require a companion soil vapor extraction (SVE) and off-gas treatment systems to treat the emanating vapors.

The operation of the proposed PABS system would be characterized by **high flow rate pulsed sparging of atmospheric air**. By using a high flow rate, the zone of airflow (or zone of influence - ZOI) for PABS can approach the zone of airflow that is experienced during conventional air sparging. The limited injection duration (several hours) greatly reduces the volume of gas that leaves the saturated zone, but still maintains the in-situ biodegradation process. More importantly, since much less gas is injected into the subsurface, an active SVE system is likely not to be required. Instead, passive vent wells connected to carbon canisters could be used to treat the emanating vapors. Figure 1 summarizes the conceptual design, system parameters, and preliminary performance analysis for the AS and PABS systems.

2.0 CONCEPTUAL DESIGN AND OPERATION OF THE SPARGING SYSTEMS

The AS and PABS systems would consist of injection wells installed at the areas of Sites G, H, and I where residual DNAPL containing aerobically-degradable constituents is most likely to exist. For the purpose of this preliminary analysis, the injection well spacing was set at 60 feet (radial ZOI assumed to be 30 feet) in the areas of residual DNAPL, which is consistent with the well spacing discussed in the CH2M Hill tech memo, “Preliminary Options for Oxygen Addition at Sauget Area 1 DNAPL Residual Areas” dated October 7, 2008. Each location would contain dual nested wells screened at approximately 52 and 104 feet below ground surface to target source material in the Middle Hydrogeologic Unit (MHU) and Deep Hydrogeologic Unit (DHU), respectively.

Recent performance data from a deep (50 to 150 feet below the water table) air sparging system showed that the ZOI increases with injection depth (Klinchuch 2007), suggesting the possibility of ZOI greater than the assumed 30 feet and consequently a reduced number of injection locations required for treatment. However, for the purposes of this preliminary performance analysis and planning-level cost estimates, a more conservative injection well spacing was used.

2.1 Air Sparging (AS) / Soil Vapor Extraction System

The air sparging system would be operated with a series of blowers or compressors supplying the injection wells with atmospheric air. A soil vapor extraction system would be coupled to the air sparging system to recover vapors escaping to the vadose zone. Preliminary design information from the AS system was used to estimate that a total of 469 soil vapor extraction wells (radial ZOI of 15 feet assumed) would be required to capture sparged air from the vadose zone (FRTR, 2007). Off gas from the SVE system would be treated using vapor phase granular activated carbon. The estimated number of wells for the air sparging / soil vapor extraction system is detailed in Table 1.

Table 1. Estimated Number of Wells for Air Sparging with Soil Vapor Extraction

Wells	Site G	Site H	Site I	Total
Air sparge wells in MHU	12	27	53	92
Air sparge wells in DHU	12	27	53	92
Soil vapor extraction wells	61	138	270	469

2.2 Pulsed Air Biosparging (PABS) System

The PABS system would consist of a series of blowers or compressors supplying the injection wells with atmospheric air. Passive vent wells would be installed to recover vapors escaping to the vadose zone. The PABS system would be operated in an on/off mode consisting of short duration (few hours), high flow (20 to 25 CFM), pulsed injections of atmospheric air conducted twice per week. The optimum duration, flow rate, and frequency of the injections, as well as the radial ZOI would be determined during the pilot test phase.

Oxygen contained in air trapped in the formation pore space can diffuse into the formation after the short period high intensity injections are stopped, and calculations indicate that 5% trapped gas can continue to deliver oxygen to the groundwater for at least one day and probably longer after the end of the injection (Leeson et al., 2002). For that reason the preliminary analysis of the system was based on 5% pore space air saturation, and when implemented the goal of the PABS system will be to establish a 5% post-injection pore space air saturation at the site.

Table 2 presents the estimated number of injection wells that would be required for the PABS system assuming well spacing of 60 feet, and radial ZOI of 30 feet.

Table 2. Estimated Number of Injection Wells for the Pulsed Air Biosparging System

Wells	Site G	Site H	Site I	Total
PABS wells in MHU	12	27	53	92
PABS wells in DHU	12	27	53	92
Passive vent wells	12	27	53	92

3.0 AIR SPARGING AND PULSED AIR BIOSPARGING SYSTEM PERFORMANCE

Preliminary analysis of the expected mass removal for the two systems was based on equations presented in the Air Sparging Design Paradigm (Leeson et al., 2002). Key model inputs and assumptions were:

- The model input value for initial soil contaminant concentration was the highest mean concentration of total VOCs plus total SVOCs at the DNAPL characterization borings. The mean concentration for each boring was calculated using results for samples from within the MHU and DHU. The highest mean concentration of total VOCs plus total SVOCs was 346 mg/kg at A1-14.
- The model input value for initial groundwater contaminant concentration was the highest observed groundwater contaminant concentration for chlorobenzene (i.e., 34,000 ug/L at location AA-I-S1 in the sample from 77-81 ft below grade).
- Volatilization was the dominant initial removal mechanism for the air sparging system, with biodegradation dominating at later operation times
- Biodegradation was the only contaminant removal mechanism for the pulsed air biosparging system

Preliminary modeling of the anticipated performance metrics of the AS and PABS systems indicate that for:

- Air sparging
  - High rate of volatilization from within the air channels will occur for approximately the first 60 days of system operation
  - Approximately 20% of the simulated initial VOC and SVOC mass will be volatilized from the air channels within the first 60 days of system operation
  - Subsequent contaminant mass removal will be achieved by aerobic degradation, with 75% of the initial mass removal estimated at approximately 2 years and 90% of the initial mass removal estimated at approximately 3.5 years.

- Pulsed air biosparging
    - Contaminant removal will lag the air sparging system due to absence of volatilization during pulsed air injections
    - Contaminant removal will also be slower over the duration of the system operation due to lower volume of oxygen available for aerobic biodegradation, with 75% of the initial mass removal estimated at approximately 3.5 years and 90% of the initial mass removal estimated at approximately 6.5 years.

The preliminary performance analysis of the PABS system reflects the assumption that contaminant mass removal will be achieved by enhanced aerobic biodegradation, with negligible contaminant volatilization into the vadose zone.

The attached figure compares predicted contaminant removal for air sparging and pulsed air biosparging based on the equations presented in the Air Sparging Design Paradigm and the model inputs and assumptions. However, it is difficult to predict the actual performance of a source treatment project prior to its application in the field (ESTCP, 2008).

In summary, the sparging model predicts that the pulsed air sparging system has about 50% of the mass removal rate as the constant air sparging system, but without the need for a surface SVE system.

4.0 AIR SPARGING AND PULSED AIR BIOSPARGING SYSTEM COSTS

Planning-level cost estimates were developed for each of the two technologies using the RACER™ Version 10.2 software. Costs were estimated for the following three primary phases of the remediation project: i) design; ii) construction and installation; and iii) operation, monitoring, and maintenance (OM&M). Other costs such as pilot testing, long-term monitoring, and site closure were assumed to be comparable for the two technologies and therefore were not included in the analysis.

The RACER software estimates design costs as a percentage of system capital costs. System construction and installation costs are estimated using conceptual design parameters (e.g., number of wells, well spacing, flow rates, etc.) and cost algorithms for each technology. Costs for OM&M activities are estimated based on assumed operational duration, sampling events, and cost algorithms for each technology. For the air sparging / SVE system, estimated costs for vapor treatment using granular activated carbon were based on an assumed average 20 ppm organic vapor concentration from the SVE system over the operating duration of the system.

The cost of electricity for operating the pulsed air biosparging equipment was assumed to be the same as the cost of electricity estimated by RACER for operating the air sparging equipment. However, the cost of electricity for operating the pulsed air biosparging equipment should be significantly lower because the pulsed air biosparging equipment only operates twice per week, whereas the air sparing system is assumed to be in operation 24 hours per day.

The operational duration of each system was assumed to be the time predicted to attain 90% removal of soluble VOCs and SVOCs based on the performance analysis presented in Figure 1. An operating duration of 4 years was assumed for the air sparging system, while a value of 7 years was assumed for the pulsed air biosparging system. Planning-level costs for air sparging and pulsed air biosparging are summarized in Tables 3 and 4.

Table 3. Planning-Level Cost Estimate for Air Sparging with Soil Vapor Extraction

Sauget Area 1 Site	Design	Construction and Installation	OM&M	Total
Site G	$87,000	$1,171,000	$1,931,000	$3,190,000
Site H	$203,000	$2,917,000	$3,255,000	$6,375,000
Site I	$388,000	$5,358,000	$5,402,000	$11,148,000
Site Wide Total	**$679,000**	**$9,446,000**	**$10,588,000**	**$20,712,000**

Table 4. Planning-Level Cost Estimate for Pulsed Air Biosparging

Sauget Area 1 Site	Design	Construction and Installation	OM&M	Total
Site G	$50,000	$649,000	$728,000	$1,426,000
Site H	$93,000	$1,363,000	$826,000	$2,282,000
Site I	$183,000	$2,644,000	$996,000	$3,823,000
Site Wide Total	**$326,000**	**$4,656,000**	**$2,550,000**	**$7,531,000**

5.0 CONCLUSIONS

The planning level analysis indicates that a high-flowrate pulsed air biosparging system has better cost characteristics compared to an air sparging system with soil vapor extraction. Preliminary analysis of the expected performance and planning-level costs for air sparging vs. pulsed air biosparging are summarized on Table 5.

Table 5. Performance and Cost Comparison of Air Sparging and Pulsed Air Biosparging

Technology	Time to 90% Removal of Soluble VOCs and SVOCs	Planning-Level Cost Estimate
Air Sparging with SVE	~ 4 years	**$20,712,000**
Pulsed Air Biosparging	~ 7 years	**$7,531,000**

As shown on the table, AS is predicted to have a shorter remediation timeframe and higher costs compared to the PABS system. Although the remediation time frame of the PABS system is approximately twice that of the AS system, the elimination of the SVE and off gas treatment systems associated with the AS will result in overall savings for the operation, maintenance and monitoring during the operation of the PABS system. Based on results of this preliminary analysis, air sparging appears to be a more effective system in terms of the contaminant removal timeframe (i.e. shorter contaminant removal time), while the pulsed air biosparging systems offers better cost performance over the anticipated system operation period.

If AS or PABS is required as a component of the site remedy, it is recommended that a pilot test be conducted prior to the implementation of a site-wide sparging system at Sauget Area 1 Sites G, H and I. The results from this test will allow for the determination of the subsurface ZOI of air and consequently provide information of performance characteristics that will be optimized for the purpose of improving the efficiency of the sparging system, and enhanced contaminant degradation.

6.0 REFERENCES

CH2M Hill, 2008. *Preliminary Options for Oxygen Addition at Sauget Area 1 DNAPL Residual Areas*. Prepared for USEPA by CH2M Hill, October 7, 2008.

ESTCP, 2008. *Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soils and Groundwater*. Developed for the Environmental Security Technology Certification Program (ESTCP) by Tom Sale, Charles Newell, Hans Stroo, Robert Hichee, and Paul Johnson, July 2008.

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Klinchuch, L.A., Goulding, N., James, S.R., and J.J. Gies. 2007. *Deep Air Sparging – 15 to 46 m beneath the Water Table*. Ground Water Monitoring & Remediation. 27(3): 118-126, Summer 2007.

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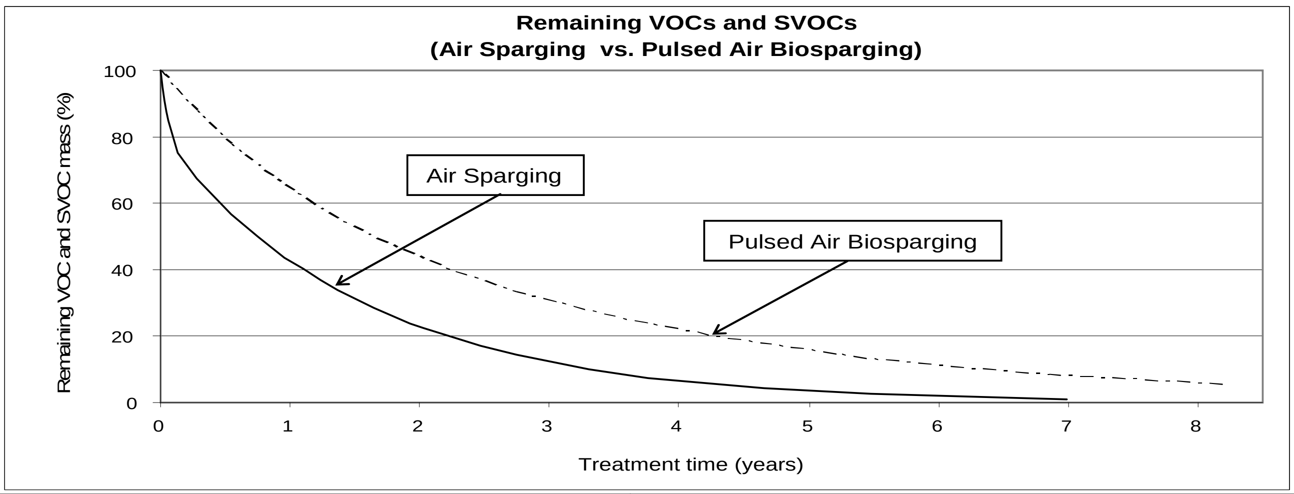
NFESC, 2001. *Air Sparging Guidance Document, Technical Report* TR-2193-ENV, Naval Facilities Engineering Service Center, Port Hueneme, California.

RACER, 2008. Remedial Action Cost Engineering and Requirements System, Version 10.2, developed and distributed by AECOM (formerly EarthTech), Englewood, Colorado.

<table>
<tr><th></th><th><u>Air Sparging (AS)</u></th><th><u>Pulsed Air Biosparging (PABS)</u></th></tr>
<tr><td>Approach</td><td>▪ Atmospheric air continuously injected into the saturated zone
▪ Air volatilizes contaminants from saturated zone to vadose zone
▪ Air delivers oxygen to saturated zone and enhances biodegradation of contaminants</td><td>▪ Atmospheric air injected (in pulses) into the saturated zone
▪ Short injection time eliminates/minimizes contaminant volatilization to vadose zone
▪ Air delivers oxygen to saturated zone and enhances biodegradation of contaminants</td></tr>
<tr><td>Key Design Parameters</td><td><table><tr><td>Air Injection Rate (SCFM)</td><td>20</td></tr><tr><td>Radial Zone of Air Distribution (ft)</td><td>30</td></tr><tr><td colspan="2">Continuous Air Injection</td></tr></table></td><td><table><tr><td>Air Injection Rate (SCFM)</td><td>20</td></tr><tr><td>Radial Zone of O_2 Distribution (ft)</td><td>30</td></tr><tr><td>Injections per week</td><td>2</td></tr></table></td></tr>
<tr><td>Performance
(based on Air Sparging Design Paradigm, Leeson et al., 2002)</td><td colspan="2">
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<tr><td>Disadvantages</td><td>▪ System will likely require SVE system and Off-Gas treatment</td><td>▪ Longer remediation time frame</td></tr>
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Figure 1. Air sparging and pulsed air biosparging system conceptual design, parameters, and preliminary performance analysis.

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PREDICTED CONTAMINANT REMOVAL (AIR SPARGING AND PULSED AIR BIOSPARGING)
SAUGET AREA 1